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A model for the investigation of the microclimate of canopies - II: Results for drying canopies

by N Thompson

1. Introduction An earlier report (Thompson 1979a) gave a detailed description of a multi-layer micrometeorological model of crop canopies which had been developed to study the drying of crop canopies after wetting by rain or dew. The model has been used more recently in a modified form to simulate the drying of cut grass in the swath (Thompson 1979b). The original model was produced in order to obtain estimates of the different rates of evaporation of dew or intercepted water at different heights within a canopy, with in mind the implications for the spread and development of fungal diseases of plants. Operational schemes used by the Meteorological Office to estimate daily the likelihood of fungal diseases developing incorporate the hypothesis that plants remain wet after rain or dew while the relative humidity at screen height remains above 90%. An experimental study reported by Smith (1962) compared duration of surface wetness in an orchard (measured by a Hirst wetness recorder) with relative humidities measured at a nearby synoptic station. The experiment confirmed that the duration of measured surface wetness was close to the period given by the 90% hypothesis. However this orchard probably formed a sparse canopy and certainly a better ventilated one compared to many crops, and it is unlikely that intercepted dew, or rain would have evaporated in much the same way from denser crops such as the cereals. The canopy model provides an opportunity to study this problem in more detail. The remainder of this paper will describe applications of the model to the drying of wetted canopies of cereals and grass.

2. Data Table 1 shows hourly observations at Honington for two periods in June 1978, each of which included fairly protracted rainfall soon followed by weather favourable to evaporation of intercepted water from plants. On the first occasion approximately 23 mm of rain fell in a 13 hour period ending at about 0840 Z. By 0900 the relative humidity had fallen to 86% and dropped a further 15% in the next two hours. A good crop of winter cereal would have intercepted about 1 mm of water during the period of rain and even if this had evaporated subsequently at a uniform rate at all levels in the crop a period of (several) hours would have elapsed before the crop was dry. Rates of evaporation of water are substantially lower deeper in the crop and the drying period would have been longer still at these heights. Clearly the 90% relative humidity criterion fails in this case to give an adequate estimate of the duration of surface wetness. On the second occasion about 2 mm of rain fell, mostly during a period of high relative humidity. The same cereal crop would have developed somewhat further by this date and would have intercepted close to 1 mm of rain again, in spite of the much lighter rainfall. Here the screen relative humidity fell below 90% about 2 hours after the rain ceased, again considerably earlier than the time when all the intercepted water would have evaporated.

In each of these two cases the rain ceased on passage of a cold front, and thus the canopy drying occurred in an advective situation. This may account in the first case in particular for the 90% criterion being rather wide of the mark. It is

Table 1 Hourly observations, Honington June 1978

	15-16 June			27-28 June		
Time of Obs (Z)	Temp (°C)	RH (%)	Hourly Rain (mm)	Temp (°C)	RH (%)	Hourly Rain (mm)
20						
21						
22						
23				11.8	81	0
00				10.6	94	0.4
01				10.4	95	0.5
02			22mm	10.3	96	0.1
03			(nearly	10.3	99	0
04			contin-	10.6	98	0
05			uous	10.8	99	0
06			rain)	11.1	100	0.2
07				11.8	100	0.4
08				12.4	100	0.3
09	12.0	86	1.0	13.4	97	0
10	13.0	80	0	16.4	87	0
11	13.8	71	0	16.3	84	0
12	14.7	65	0	17.8	78	0
13	14.9	67	0	18.4	57	0
14	14.2	72	0	19.0	56	0
15	15.3	65	0	20.1	55	0
16	14.8	66	0	19.8	55	0
17	15.0	68	0			

probable that where rainfall or deposition of dew occurs in a homogeneous airmass the time when relative humidity falls to about 90% is likely to give a better indication of the drying out of at least the upper part of the canopy than when advection is occurring. In practical operational warming schemes of plant/disease weather such as that run daily on the Bracknell computers it is impossible to distinguish the effects of airmass changes on likely drying rates, and in these circumstances a much superior alternative to the 90% criterion is unlikely to be found. What may be done however is to run the crop canopy model with synoptic data to obtain some indication of the disparity of duration of leaf wetness from the 90% criterion compared to likely durations at different levels within the canopy calculated by the model. The data to be used are those for the two periods just described and also for a third period in which dew was known to have formed. This last case was one of those described by Smith (1962) for an orchard. More detailed studies in potato canopies (Hirst et al 1953) and in wheat (Penman and Long 1960) have demonstrated that when dew forms there is usually water vapour transport downwards above the crop and upwards within it, perhaps suggesting that dew is often deposited throughout the plant canopies. However radiational cooling of the canopy will be greatest at its upper surface and one expects therefore maximum deposition of dew at the top of the crop. Monteith (1973) suggests that maximum dewfall in a single night will be around 0.4 mm and with the higher value in particular the interception capacity of the upper foliage may be exceeded and some dripping and wetting of lower leaves will occur. In most cases though the dew deposit will be less and the amount of drippingnegligible, and in these circumstances the variations of subsequent drying rates at different heights

within the (upper) part of the canopy which is wet would probably be small. Here a simple criterion of duration of surface wetness such as the 90% relative humidity criterion might be expected to be more consistently successful.

3. Model results and discussion

3.1 Simulation of evaporation of intercepted water from cereals.

Table 2 gives the relative distribution of leaf area index assumed for the cereal canopies of the simulations. Maximum leaf area was assumed

Table 2 Distribution of leaf area in the model cereal canopies

Relative height (1.0 ≡ top of canopy)	Relative leaf area in each layer
.94	0.9
.81	1.0
.69	1.0
.56	0.9
.43	0.8
.31	0.6
.19	0.4
.06	0.3
	TOTAL LAI 6-7

to be at three quarter height in the canopy, with a standard deviation of distribution about this height of 0.45h (h = height of canopy). An interception capacity of 0.2 mm per unit leaf area was assumed.

3.1.1 16 June 1978

The simulation was started at 0900 with a saturated canopy. Table 3 shows the calculated amounts of intercepted rain remaining in each layer at 20-minute intervals from 0900. The lower part of the crop was calculated to be still wet 5 hours after the cessation of the rain, and evaporation of water from the lowest two layers in this period was very small. The results are dependant on the exact distribution of leaf area in the canopy - for example a sparser upper canopy would lead to more rapid drying of the foliage there. Nevertheless there is in these results a very clear indication of very slow rates of drying of the middle and lower parts of fairly dense canopies. The rate of drying appears to be exaggerated by the model which calculated a consistently downward flux of sensible heat to the canopy, thus increasing the energy for sustaining an upward water vapour flux from the crop. The Honington screen temperature rose steadily from 0900 and so the calculated downward flux of sensible heat was spurious and the result probably of assuming that the 10 m wind over the cereal was the same as that measured over a grass-covered surface at Honington. Thus the calculated rate of evaporation of surface water from the canopy was probably an overestimate, indicating that the simulated duration of

Table 3 Intercepted water in each layer at 20-minute intervals, cereals 16/6/78

Layer mid-height (m)	Intercepted water in layer (mm)								
	0900	0920	0940	1000	1020	1040	1100	1120	1140
0.75	.181	.165	.148	.126	.097	.059	.015	0	0
0.65	.196	.187	.177	.165	.147	.125	.099	.069	.032
0.55	.196	.191	.186	.180	.171	.159	.145	.129	.109
0.45	.181	.179	.176	.173	.168	.163	.156	.148	.138
0.35	.154	.153	.152	.150	.148	.145	.142	.138	.134
0.25	.121	.121	.120	.120	.119	.117	.116	.114	.112
0.15	.088	.088	.088	.087	.087	.086	.086	.085	.084
0.05	.059	.059	.059	.059	.059	.058	.058	.058	.057
	1220	1220	1240	1300	1320	1340	1400	1420	1440
0.75	0	0	0	0	0	0	0	0	0
0.65	0	0	0	0	0	0	0	0	0
0.55	.089	.061	.031	0	0	0	0	0	0
0.45	.129	.115	.100	.086	.067	.045	.025	.005	0
0.35	.129	.123	.117	.110	.101	.091	.081	.072	.058
0.25	.110	.107	.104	.101	.097	.092	.088	.084	.078
0.15	.083	.082	.080	.079	.077	.075	.073	.071	.069
0.05	.056	.056	.056	.055	.055	.054	.053	.052	.051

leaf wetness was too short (the maximum available energy over the 5-hour period after cessation of rain was estimated to be less than (160 Wm^{-2} because of substantial amounts of cloud - clearly the rate of evaporation of surface water would have been substantially larger had a nearly cloudless day followed the rain).

3.1.2 28 June 1978

The preceding night was dull and humid with two spells of mainly light rain (Table 1). The second period of rain ceased at about 0900 but cloud did not decrease to small amounts until the early afternoon. Calculated evaporation of intercepted water was very small until after 0900 (Table 4). At this time the canopy had intercepted nearly its maximum capacity of water (cf Table 3 for a canopy with leaf area index (and hence maximum interception) about 15% less). After 0900 the canopy dried steadily but three hours after rain ceased most layers still remained wet. At this time about 65% (0.8 mm) of the intercepted water had evaporated.

Table 4 Intercepted water in each layer, cereals 28 June 1978

Layer mid-height (m)	Intercepted water in layer (mm)								
	0000	0100	0200	0300	0400	0500	0600	0700	0800
0.84	.111	.144	.146	.185	.178	.169	.166	.195	.203
0.73	.092	.147	.156	.196	.192	.187	.187	.216	.220
0.62	.052	.130	.141	.177	.175	.172	.174	.199	.220
0.51	.028	.103	.113	.142	.141	.140	.142	.162	.203
0.39	.014	.055	.079	.105	.104	.104	.105	.120	.157
0.28	.008	.028	.041	.072	.072	.071	.073	.083	.108
0.17	.004	.015	.022	.043	.043	.043	.046	.054	.071
0.06	.002	.008	.012	.023	.023	.023	.025	.033	.044
	0900	0920	0940	1000	1020	1040	1100	1120	1140
0.84	.197	.181	.152	.109	.052	0	0	0	0
0.73	.217	.207	.189	.163	.128	.092	.043	0	0
0.62	.219	.213	.203	.189	.169	.149	.122	.093	.052
0.51	.202	.199	.195	.187	.177	.167	.152	.137	.116
0.39	.172	.171	.168	.165	.160	.155	.148	.140	.130
0.28	.128	.127	.126	.124	.122	.120	.116	.113	.108
0.17	.084	.083	.083	.082	.081	.080	.078	.077	.075
0.06	.052	.052	.051	.051	.051	.050	.050	.049	.048

3.1.3 Discussion of results for cereals

The assumed leaf area indices (nearly 6 and nearly 7 respectively) and the interception capacity per unit leaf area of 0.2 mm may be rather high for typical cereals. A further simulation was run for 16 June assuming now an interception capacity of only 0.1 mm per unit leaf area. The top layer was now calculated to dry out by 1020 (one hour earlier) and the fourth layer by 1220 (nearly $2\frac{1}{2}$ hours earlier). Even so the lowest layers still dried very slowly, finally drying out 8 hours after rain ceased. Halving the leaf area would also have accelerated the drying out because most of the radiation incident on the canopy would still have been intercepted by it, leading to available energy only slightly less than before. Nonetheless the evidence from these simulations is that for typical mature cereal canopies thoroughly wetted by rain, the time for the lowest layers to dry will be some hours longer than that given by the 90% relative humidity criterion. This is supported in a general way by some comments of Hirst (1957) who found when testing two types of wetness recorder in a potato crop that the instruments indicated a shorter period of surface wetness than occurred for the lower foliage of the potatoes (the sensitive surfaces of the instruments had been placed at or just above the crop foliage).

3.2 Rainfall and dew on grass, and subsequent evaporation

3.2.1 16 June 1978

The model was run for two simulations of dense short grass 0.1 m high, first assuming that the leaf area was normally distributed about mid-height, and second about 0.025 m, in each case with standard

deviation 0.04 m. The leaf area indices were respectively 3.6 and 3.2, and interception was 0.2 mm per unit leaf area. Results for the first case are given in Table 5. The drying-out took place at a somewhat faster rate than for cereals, partly reflecting the

Table 5 Intercepted water (mm) in each layer at 20-minute intervals - dense short grass

Layer mid-height (m)	Intercepted water in layer (mm)								
	0900	0920	0940	1000	1020	1040	1100	1120	1140
.094	.062	.058	.052	.043	.033	.020	.005	0	0
.081	.083	.079	.073	.065	.054	.042	.028	.011	0
.069	.100	.097	.092	.085	.076	.066	.054	.040	.025
.056	.110	.108	.104	.099	.092	.084	.075	.065	.054
.043	.110	.108	.106	.102	.098	.092	.086	.079	.072
.031	.100	.099	.097	.095	.092	.089	.085	.080	.076
.019	.083	.082	.081	.080	.078	.076	.073	.071	.068
.006	.062	.062	.061	.060	.059	.058	.057	.055	.054
	1200	1220	1240	1300	1320	1340	1400	1420	1440
.094	0	0	0	0	0	0	0	0	0
.081	0	0	0	0	0	0	0	0	0
.069	.007	0	0	0	0	0	0	0	0
.056	.042	.028	.012	0	0	0	0	0	0
.043	.064	.056	.045	.035	.022	.009	0	0	0
.031	.071	.066	.060	.054	.046	.039	.032	.025	.015
.019	.065	.063	.059	.056	.051	.047	.043	.039	.034
.006	.052	.051	.049	.047	.044	.042	.040	.038	.035

smaller intial interception of water, but the top 5 layers still required about 5 hours to lose all their water. The initial distribution of water in the second case favoured earlier drying in the upper canopy and this advantage was maintained throughout: for example 3 hours were needed for the top 5 layers to dry, and after 6 hours less than 0.05 mm remained, in the lowest two layers, compared to 0.085 mm in the lowest 3 layers of the canopy symetrically distributed about mid-height. Simulations of the drying of a canopy of twice the height and twice the leaf area, distributed as in the first case, show very slow drying of the lowest layers, with the fifth layer still wet after 7 hours.

These and the earlier results suggest that following substantial rainfall (several millimetres) the 90% humidity criterion gives no reliable indication of the duration of leaf wetness, not even in the highest layers of a canopy. However the situation regarding the duration of leaf wetness following dewfall may be substantially different. Maximum likely dewfall is around 0.4 mm and so leaves will dry faster than after substantial rainfall. Smith (1962) included a diagram showing the variation with time of the amount of water accumulated by a surface wetness recorder on a dew night, and the evaporation of this water the following morning. The recorder was exposed in an orchard

towards the end of March and so trees would still have been leafless. There was no indication in the paper of height of exposure of the instrument but the results may be compared qualitatively with a simulation for long grass (assumed to comprise the orchard floor). Figure 1 shows the mass of water accumulated by the surface wetness detector (in arbitrary units) and the corresponding results from the simulation (by summing the calculated surface moisture in all the model layers): meteorological data were from Felixtowe, about 30 km from the orchard. Winds were very light during the night and the three-hourly observations used to interpolate the model inputs reported calms at 00, 03, 06 and 09Z. However the model was unable to treat cases with zero wind speed and so a lowest value of 1 kt was used: the stopping speed of a standard anemometer is probably 2 or 3 kt and a reported calm will often correspond to a light wind below stopping speed. Monteith (1957) showed that genuine dew deposition became small on very calm nights although "distillation" of water vapour from the soil onto the grass would still have occurred. The model results probably exaggerate slightly therefore the total vapour transfer to the grass by maintaining too high a level of turbulent mixing above the grass-covered surface and hence transfer of vapour downwards. However the patterns of water accumulation by the wetness recorder and calculated by the model up to the time when evaporation began (around 07Z) are clearly very similar.

The vertical distribution of surface water calculated by the model during the nighttime period showed water accumulating at all levels within the canopy whereas one might expect "dewfall" chiefly in the upper part. However the model's treatment of turbulent mixing in the canopy was similar for both day and nighttime cases, which is not likely to be realistic. In particular the soil surface is usually warmer than the canopy at night and this encourages enhanced turbulent (convective) mixing: however in the absence of a simple, realistic method of taking this into account the limitation has to be accepted. Also the method by which the surface temperature is calculated, which relies heavily on the crude estimates of turbulent mixing, leads to unrealistically high surface temperatures on very still nights. This in turn affects the distribution of intercepted water in the canopy, although the total deposit may be comparatively little affected since the upward flux of water vapour from the surface depends largely on the arbitrarily-estimated soil heat flux and whether or not the soil surface was wet or dry (it was assumed to be moist in the present calculations because of rain in the period preceding the simulation).

Figure 1 shows that after 07Z the wetness detector dried out much more rapidly than the simulated canopy, indicating the much better drying of a single well-exposed surface compared to a complex canopy.

4. Concluding remarks

It has not been possible to verify the simulations of canopy drying with field data from crops, but the results presented here are in qualitative agreement with experience. In particular the performance of a well-exposed wetness detector is unlikely to be representative of the drying of a dense canopy such as the cereals, gives no indication of the very low rates of drying near the ground surface in

canopies, and can at best give only a rough indication of cropy drying in very sparse canopies such as orchards. There is no justification for assuming that the 90% relative humidity criterion will provide a satisfactory indication of the duration of leaf wetness in an entire cereal canopy especially following rainfall of a millimetre or more - it is only likely to be of value in the case of cereals for occasions of light "dewfall" and even here the assumption is needed that such "dew" will be confined to the highest layers of the canopy.

Any comments or suggestions on this paper should be referred to the author.

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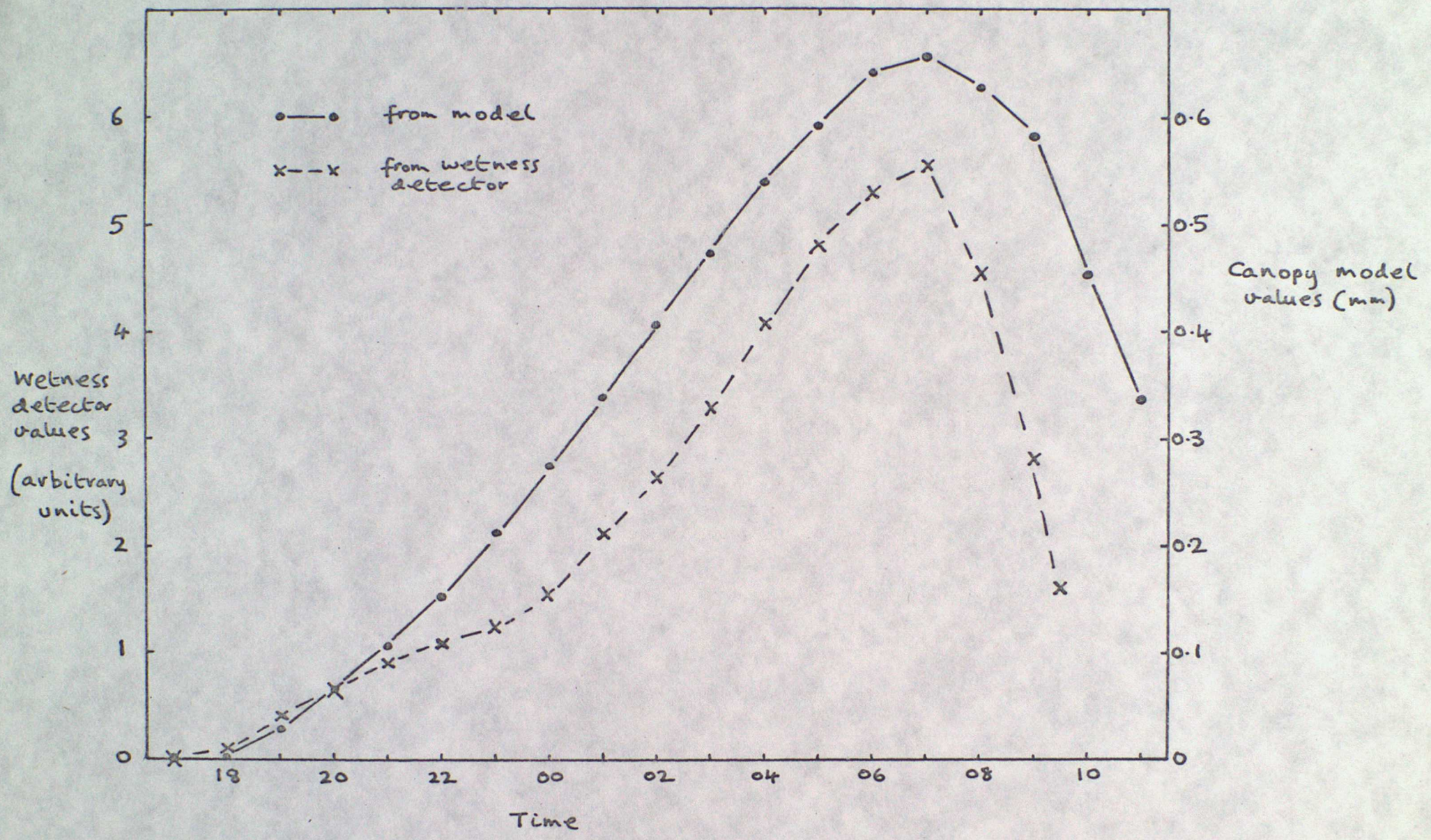

Figure 1 Measured and simulated accumulated surface water 21–22 March 1957